Inquiry: The University of Arkansas Undergraduate Research Journal

Volume 17 Article 6

Fall 2014

Covered Interest Parity Empirical Analysis of Non-Traditional Monetary Policy's Effects on Exchange Rates

Tyler Salminen
University of Arkansas, Fayetteville

Covered Interest Parity Empirical Analysis of Non-Traditional Monetary Policy's Effects on Exchange Rates

By Tyler Salminen
Department of Economics

Faculty Mentors:
Dr. Javier Reyes, Office of the Provost and Vice Chancellor for Academic Affairs
Dr. Jingping Gu, Department of Economics

Abstract

This research sought to find an economically justifiable relationship between non-traditional monetary policies of the Bank of Japan and the Federal Reserve and the dollar/yen exchange rate. This research utilized the covered interest parity condition in conjunction with a partial least squares structured equation analysis in order to discern any possible relationships between these two phenomenon. A solid relationship between the non-traditional monetary policies of these central banks and dollar/yen exchange rate was found. In order to analyze significance, direction, and nature of this relationship this research followed up the partial least squares analysis with bootstrap structural equation modeling. Because of the linear nature of this method of evaluating relationships, it was difficult for this research to discern a consistent and significant pattern in the relationships found in the partial least squares analysis. Future research into this topic should be directed towards exactly identifying the nature and method for which these policies affect the exchange rate.

Introduction

Proceeding the beginning of the recent financial crisis, large central banks like those in Japan and the U.S. resorted to implementing non-traditional macro-policies like quantitative easing and credit easing in an attempt to jumpstart underperforming domestic markets. However, these policies are currently understudied; it is important to asses them since they could have the effect of depreciating a country's domestic currency relative to others due to the deliberate depression of market interest rates in countries employing these policies. The cases of Japan and the U.S. were used to develop an empirical study seeking to determine any possible interactions these policies may have on currency markets.

A structured empirical analysis, split into two hypotheses to analyze the relationship recognized above was developed. The first hypotheses sought to identify if a relationship even existed between Bank of Japan (BoJ) and Federal Reserve (FED) operations and exchange rates. The second sought to define a particular mathematical relationship, for the purpose of identifying how these operations interacted with exchange rates.

Using balance sheet data and various other data measures, structured statistical models in SmartPLS were formed based upon the CIP (covered interest parity condition) economic theory. Then, the PLS algorithm of SmartPLS was applied, using two different, two week running windows, to these structured statistical models. This modeling process analyzed the movements of these central banks' balance sheets to determine if there was matching variation in the exchange rate between the dollar and the yen over time. A strong and contiguous relationship was found. Next, the SmartPLS bootstrap algorithm was applied to these same structured models but with different time delineations based on significant FED quantitative easing (QE) dates. The bootstrap algorithm failed to define a significant, linear relationship between balance sheet holdings and exchange rates. Further research should be directed into defining the particular method in which movements in the balance sheet holdings of central banks affect exchange rates.

Theoretical Framework

In this section, the theoretical framework for this research study is described. It includes how a general economic model was constructed using the CIP to theoretically connect balance sheet holdings of the FED and BoJ with the dollar/yen exchange rate; this model was adapted to the SmartPLS program for subsequent statistical analysis. It will also be explained how co-linearity was systematically controlled

Inquiry: The University of Arkansas Undergraduate Research Journal, Vol. 17 [2014], Art. 6

throughout a series of four models used in the final analysis. Furthermore, it will be explained why these four separate models were chosen. Two of the models were applied to the PLS algorithm while the other two were applied to the bootstrap algorithm. Two equations, one for the PLS algorithm and one for the bootstrap algorithm, along with accompanying general statistical model figures, will be used to guide the reader into how this theoretical frame work was used to appropriately measure the theoretical relationship between balance sheet holdings of central banks and currency markets. They will also help the reader to evaluate the efficacy of the hypotheses proposed in the introduction of this paper.

The CIP is the derivation of this paper's economic, empirical model. In addition, it is the base upon which this work's statistical model garners its real-world association. The CIP was chosen for its ability to serve as a simple approach for hypothesizing economic causal relationships from one domestic market for a currency to another and for its strong ability to predict long-term fluctuations in exchange rates given highly contiguous and frequent data (Taylor, 1987). The CIP served as the essential theoretical framework for drawing relationships between central bank balance sheet movements and exchange rates for this paper. Nevertheless, in order to insure the validity of this model and its ability to compose a theoretical relationship between balance sheet holdings and exchange rates, a model containing all endogenous and exogenous variables theoretically relevant to the question of currency exchange rates, domestic security yields of Japan and the United States, and each country's monetary programs was constructed in order to systematically confiscate, manipulate, add, or alter particular variables or sets for the purpose of ensuring statistical and economic validity.

Referring to Figure 1, a composition of five security yields were collected that represent available security classes in both countries as well as being security classes somewhat differentiable from each other. This composition of securities from each country were to represent the domestic nominal interest rates of the U.S. and Japan as defined in the CIP equation as $i_\$$ and $i_¥$ $\left(\frac{(1+i_\$)}{(1+i_¥)} \times E^{\$}_{¥} = F^{\$}_{¥}\right)$.

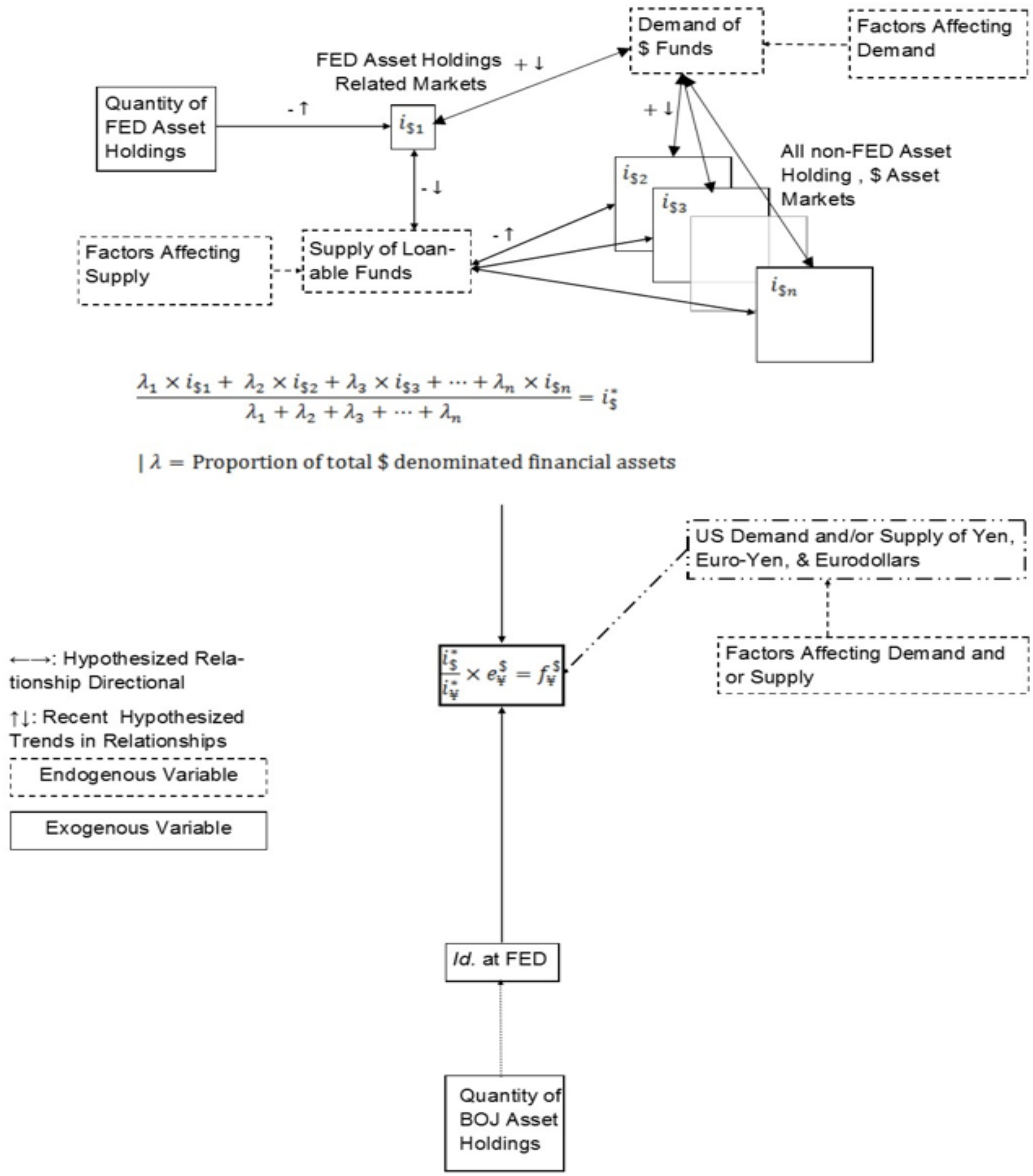
Next, the central bank was introduced as an independent actor endogenous to the model. Changes in balance sheet holdings of securities relevant to the central bank's particular monetary programs defined its role in the model as a demander and/or supplier of loanable funds. These changes in balance sheet holdings are a direct consequence of demand and supply of loanable funds by the central banks into the financial markets for those securities. Other suppliers and demanders of these securities define exogenous variables and are not of interest to this research. Because the other participants in these financial markets have explicit effects on security yields, it was the purpose of this model to measure the specific efficacy of the central bank's balance sheet holdings changes on security yields using the SmartPLS structured statistical algorithms.

The basic shape of the final CIP model is symmetrical, in that, the indicators and structural shape of the U.S. side of the model is identical to the Japan side, while both coalesce into a CIP defined exchange rate. This does not include the individual latent indicators as part of the various data sets employed by this paper; these indicators differentiate themselves with respect to each country depending on each central bank's class of securities held over time. In the final model, this exchange rate does not represent the strict mathematical current exchange rate represented in the CIP, but the future observed rate (i.e. the future exchange rate relative to the measured date of the nominal interest rate and the balance sheet holdings of the BoJ and FED).

This research used the SmartPLS program's modeling interface and various statistical literature to derive the statistical structure of the final model (i.e. the mathematically derived structure). The basic economic model based on the CIP was adapted to the type of path structuring governed by the SmartPLS software. Figure 1 represents a basic interpretation of this statistical method, Figure 2 is an actual screenshot example of the type of model employed in SmartPLS. One such adjustment made to the economic model to import it into SmartPLS was to exclude other suppliers and demanders of loanable funds from the statistical model as exogenous to this research's objective. The particular statistical method employed by this paper theoretically justifies the exclusion of these other actors.

Furthermore, in Figure 1, lambda (λ) denotes representations of factor loadings for individual security yields. For the example in Figure 1, the formula of the security yield construct represents linear combinations

Figure 1. *Sketch of the CIP based economic model including all endogenous and exogenous variables.*

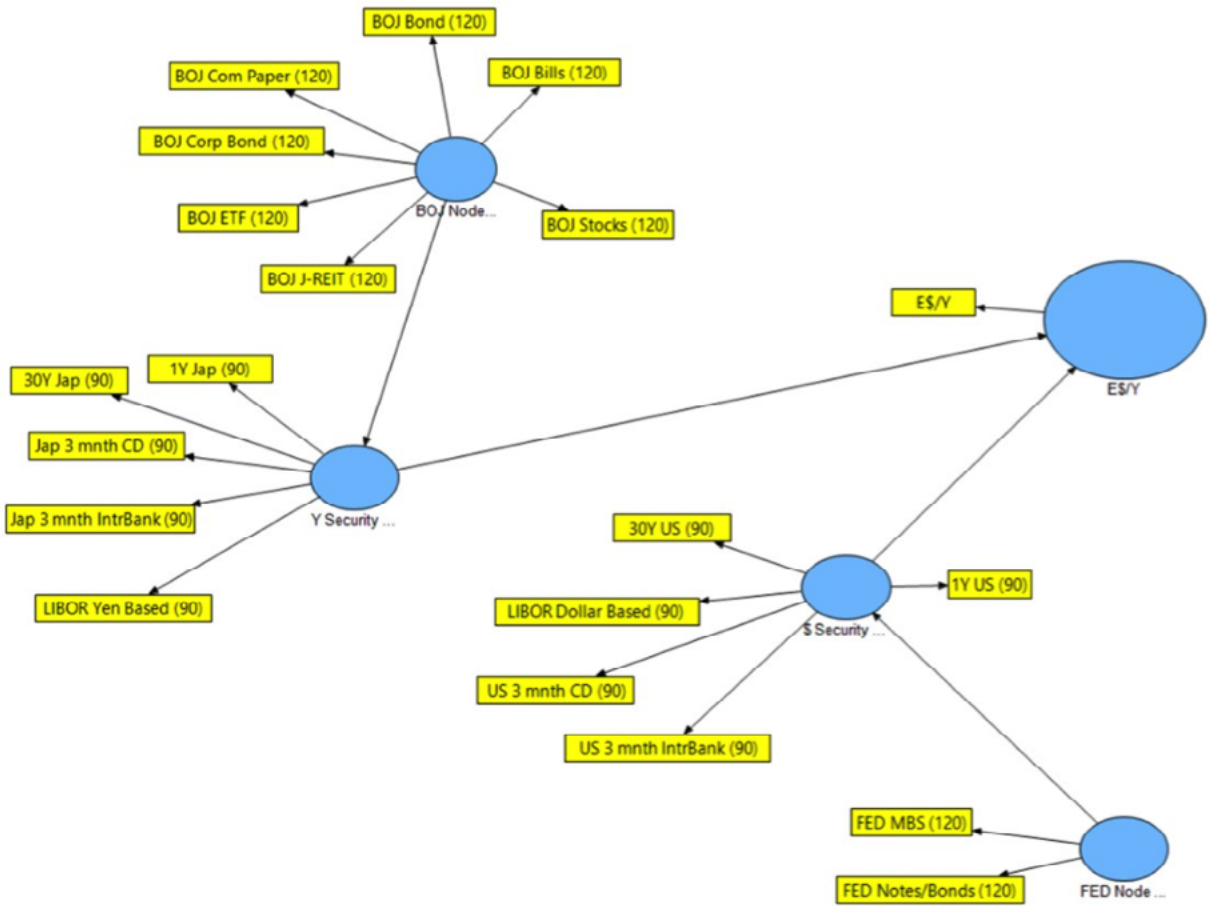


of these factors. λ is the specific variance of each latent variable (security yield in this case) extracted that is then used as a factor in a linear combination that defines the theoretical path between the exchange rate construct and the given currency denominated security yield construct. Holistically, you can think of the formula in Figure 1 as a pseudo-weighted average of a given country's domestic currency denominated security yields for a given point in time. This method of defining the CIP within a statistical framework about interest rates of a given country holds up empirically on average (Thornton, 1989).

This weighted average can represent the domestic nominal interest rate of the respective country. From the set of factor loadings, SmartPLS can derive multiple quality criteria such as AVE, cronbach's alpha, and composite reliability. These criteria can assess the likelihood that the set of individual latent variables

Inquiry: The University of Arkansas Undergraduate Research Journal, Vol. 17 [2014], Art. 6

Figure 2. Screenshot of structured statistical model is adapted to SmartPLS



should be a representative part of a particular construct. In practice, thresholds for structured models in PLC were Factor Loading > 0.63 [very good] (Tabachnick & Fidell, 2007), AVE > 0.5, Composite Reliability > 0.7, and Cronbach's Alpha > 0.7 (John, 2002). An outcome below a defined threshold for these quality criteria would warrant the removal of low factor load scoring latent variables. This concept was very important as it helped to shape the inclusion or exclusion of particular variables during set periods throughout the multiple statistical sets administered in the SmartPLS program. To elaborate, given a particular measurement within a dataset of a certain period, not all data collected for the asserted statistical model would be relevant for that period. For example, the BoJ did not hold significant positions in commercial paper until 1/22/2009. Because of this, factor loadings for that variable up until that time would result in 0.000. This would warrant the indicator's removal from the model up until 1/22/2009.

The SmartPLS program was also important for deeming the dates at which the CIP formula was most empirically viable. In order to adjust for the CIP's inability to predict short-term exchange rate fluctuations, this research placed lags between all model constructs, both between central bank balance sheet holding measurements and security yield measurements, and between security yield measurements and exchange rate measurements. The lags essentially allow a significant amount of time for investors to hedge or cover their positions so that the economic model of this research is not working within the theoretical model of the Uncovered Interest Parity Condition (UIP), which itself does not hold up to empirical verification (Chaboud & Wright, 2004). The CIP does hold during such lags as long as high frequency, high-quality data are used (Taylor, 1987). This paper used lags of 120 days, 90 days, and 30 days placed between particular data nodes in certain data sets. Table 1 outlines which particular data sets employed by this research used which lags. These lags were determined through a series of

Table 1

Summary of Models

Model	Purpose	Time Frame	Lags: Type	Lags: Period	# of Sets	Missing Data	Quality Thresholds: $\lvert f_i \rvert >$ 0.63[a]	Quality Thresholds: $t_a >$ 2.0[b]
A. 2 week running window PLS	correlation of central bank balance sheet holdings with variance in spot	6/23/2009 – 5/7/2013	Holdings to Spot	120 days	102	Earliest Measure	Yes	N/A
			Yields to Spot	90 days				
B. 2 week running window regression (alternate)	Offer alternative lag dates to project A. for confirming optimal CIP lags	6/23/2009 – 5/7/2013	Holdings to Spot	30 days	102	Earliest Measure	Yes	N/A
			Yields to Spot	30 days				
C. Total time bootstrap analysis	Estimate regression weights for purpose of evaluating hypotheses	3/25/2009 – 5/15/2013	Holdings to Spot	120 days	1	Earliest Measure	Yes	Yes
			Yields to Spot	90 days				
D. FED project date delineated bootstrap analysis	*Id.* at Model C purpose.	3/25/2009 – 5/15/2013	Holdings to Spot	120 days	8	Earliest Measure	Yes	Yes
			Yields to Spot	90 days				

[a] Statistically significant factor loadings for the purpose of evaluating the relevance of a particular variable to the presented statistical model are shown to be 'very good' when the absolute value of the factor loading is greater than 0.63 (Tabachnick, 2007).
[b] Bootstrap population estimations between constructs are considered statistically significant if the t-statistic is greater than 2 (John, 2002, pp. 305-335)

statistical analyses in SmartPLS using small subsets of data from 11/25/2008 (beginning of QE 1 program) and ending 5/15/2013 (Federal Reserve Bank of St. Louis, 2013). The next section will elaborate on how the general statistical model, economically justified by the CIP, was methodologically developed into the final analysis. It is broken up into two sub-sections, one defining the method in which this structural model was employed by the first hypothesis of this paper, which utilized the PLS algorithm, and then by the second hypothesis, which utilized the bootstrap algorithm.

Hypothesis 1 Methodology: Partial Least Squares Structural Equation Modeling

Two models were used for evaluating the existence of a relationship between balance sheet holdings of the FED and the BoJ and the dollar/yen spot rate. Referring to Table 1, these are models A and B. Model A utilizes lags placed between data nodes in order to reduce the potential effects of autocorrelation (30 days from balance sheet measurement date to security yield date and 90 days from security yield date to spot rate). Model B utilizes an alternate set of lags for the purpose of comparison to insure that the statistically derived lags for model A in fact hold up empirically (30 days from balance sheet measurement date to security yield date and 30 days from security yield date to spot rate). If the computed lag dates are indeed optimum then Model B's results should approximately represent the tail end of a normal curve that represents the variance accountancy of balance sheet holdings with respect to changes in date lags. Model A's relationship parameters, on the other hand, should exist near the 50th percentile of the distribution, or the mean. Refer to Table 1 for the exact dates of lags utilized in both models.

Both models A and B are 2-week running windows starting 6/23/2009. However, each uses measurements taken earlier due to the 120 lag placed on the balance sheet holding measurements and 90 day lag placed on the security yield measurements (Balance sheet holding and security yield measurements started 11/25/2008). Both models contain 102 distinct datasets. Each dataset contains a total of 120 days of measurements for each indicator discussed earlier. Each dataset was computed using an identically structured model to Figure 2 albeit with indicators of differing measurement dates (refer to Figure 3 for the general outline of the models used in these two models). Each data set contained a series of three computations for the purpose of reducing co-linearity. Figures 3, 4, and 5 are the general mathematical models of which these three computations were computed. Each figure corresponds to one unique computation.

Figure 3 is a non-manipulated mathematical representation of the CIP defined economic framework.

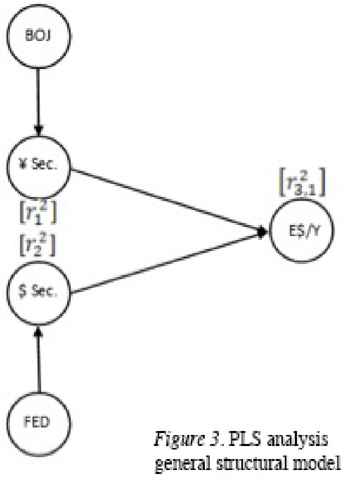


Figure 3. PLS analysis general structural model

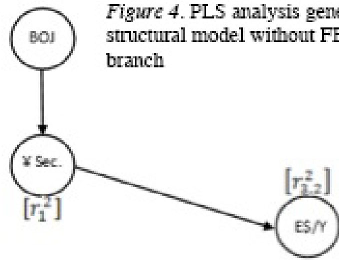


Figure 4. PLS analysis general structural model without FED branch

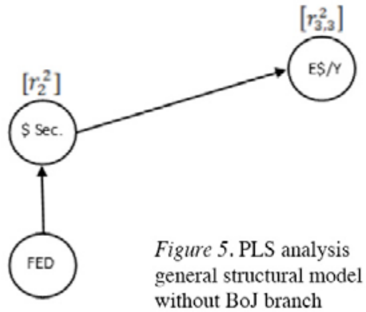


Figure 5. PLS analysis general structural model without BoJ branch

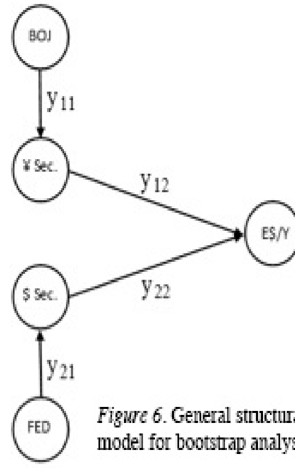


Figure 6. General structural model for bootstrap analysis

Figures 4 and 5 are manipulated models that were used to compute individual correlations between each central bank's balance sheet holdings and the dollar yen exchange rate. Referring to Equation 1, these manipulations are done for evaluating individual cases where the sum of the individual simplified, manipulated cases were greater than, or less than or equal to the congregated, non-manipulated model. There were a total of two cases that required adjustment, utilizing the aforementioned equation and figures, in order to adjust for co-linearity among nodes in the statistical model.

In one case, Case_2, the sum of the two central banks' balance sheet holdings 's correlation coefficient with the spot rate was greater than when the two central bank's balance sheets were both factored into the model at the same time (e.g. Figure 3). In another case, Case_1, the sum of these correlation coefficients are less than those in Figure 3. Co-linearity between interest rate nodes and the spot rate can possibly explain Case_2; this can happen when one construct depends on two or more other constructs. A lack of prediction power in the model where correlation coefficients are exceedingly low can possibly explain Case_1.

Equation 1 presents these two cases. It also describes how this research mathematically adjusted for each. Equation 1 denotes these two cases, Case_1 and Case_2. Equation 1's various variables are directly related to those in Figures 3, 4, and 5. In both cases 1 and 2, the correlation coefficient of the relationship between the central bank's balance sheet holdings construct with the interest rate construct was multiplied with the correlation coefficient of the relationship between the interest rate construct and the spot rate construct. However, in Case_2 extra steps were taken to adjust for possible co-linearity introduced into the model as was described with Case_2.

Equation 1. The set of computations that adjusted for possible co-linearity introduced by the structured statistical model when using the PLS algorightm in SmartPLS:

r^2 = Correlation Coefficient

BOJ: E$ /¥ = Correlation Coefficient of BOJ with E$ /¥

FED: E$/ ¥ = Correlation Coefficient of FED with E$ /¥

$$\text{Case}_1 \Rightarrow \quad r_{3,2}^2 + r_{3,3}^2 \leq r_{3,1}^2$$

$$\text{BOJ: E\$/ ¥} = r_{3,2}^2 \times r_1^2$$

$$\text{FED: E\$/ ¥} = r_{3,3}^2 \times r_2^2$$

$$\text{Case}_2 \Rightarrow \quad r_{3,2}^2 + r_{3,3}^2 > r_{3,1}^2$$

$$\xi = (r_{3,2}^2 \vee r_{3,3}^2) - r_{3,1}^2 = r_{3,2}^2 \wedge r_{3,3}^2$$

$$\text{BOJ : E\$/ ¥} = r_{3,2}^2 \times r_1^2$$

$$\beta_{1,f} \in \mathrm{B} = \left[\left(\frac{\sum_{j=1}\alpha_{2,j}}{\sum_{i,j=1}\alpha_{i,j}}\right)\times\left(\frac{\sum_{j=1}\alpha_{2,j}}{2}\right), \left(\frac{\sum_{j=1}\alpha_{1,j}}{\sum_{i,j=1}\alpha_{i,j}}\right)\times\left(\frac{\sum_{j=1}\alpha_{1,j}}{2}\right)\right]$$

$$\alpha_{i,j} \in \mathrm{A} = \begin{bmatrix} \text{BOJ : E\$/¥} & \text{BOJ : E\$/¥}\times\xi \\ \text{FED : E\$/¥}\times\xi, & \text{FED : E\$/¥} \end{bmatrix}$$

$\beta_{1,1}$ = Adjusted FED Correlation with E$/ ¥
$\beta_{1.2}$ = Adjusted BOJ Correlation with E$/ ¥

$$H_0 : \beta_{1,1} = \beta_{1.2} = 0$$
$$H_1 : \beta_{1,1} > 0 \wedge \beta_{1.2} > 0$$

In order to reduce this co-linearity, Models A and B employed a set of computations to mathematically count two extreme outcomes of thestructured statistical model accountancy of balance sheet holdings correlation with dollar/yen exchange rate variation over time. For example in one instance, the BoJ's balance sheet holdings r^2 with the spot rate node was held constant and the FED's balance sheet holdings r^2 with the spot rate were assumed to accommodate all co-linearity. The difference in the sum of these two correlation coefficients in Figures 4 and 5 and the correlation coefficient in Figure 3 from the correlation coefficient computed for the FED in Figure 5. In other words, this counting computation biased the correlation coefficient of the spot rate in Figure 3 ($r_{3,1}^{2}$) to favor the BoJ's balance sheet holdings variance. Likewise, a similar computation favored correlation coefficient $r_{3,1}^{2}$ with that of the FED's balance sheet holdings variance. Equation 1 represents these biases as a set matrix denoted A.

After counting these two extreme cases, the model computed a pseudo-weighted average, weighted based on the percent degree at which one central bank's correlation coefficient, in both bias cases, encompassed the combined correlation coefficient measurement of the two bias cases;

[$\left(\frac{\sum_{j=1} \alpha_{2,j}}{\sum_{i,j=1} \alpha_{i,j}}\right)$: Example for FED from Equation 1].

The model then scaled the average of the individual bank's correlation coefficients

[$\left(\frac{\sum_{j=1} \alpha_{2,j}}{2}\right)$: Example for FED from Equation 1].

The point of this was to congregate the set A in Equation 1 into two easy to compare correlation coefficients that adjust based on the degree that one central bank's programs overpowered the other's. In the case that the two program's individual correlation coefficients were similar, the pseudo-weighted average would merely serve the purpose of congregating the set A.

The model used a set of hypotheses to evaluate these two cases. The bottom of Equation 1 lists these hypotheses. H_0 represents the null hypothesis and H_1 represents the alternate hypothesis. These hypotheses mainly serve the purpose of evaluating the equation set of Equation 1 and not necessarily for evaluating the question as to whether there exists a relationship between balance sheet holding movements and exchange rates as is the purpose of this model. Nevertheless, the hypotheses presented in Equation 1 and the PLS algorithm in SmartPLS, combined, provide the framework and evidence for which to subsequently evaluate the possibility of any relationship existing between balance sheet holdings and exchange rates.

Hypothesis 2 Methodology: Bootstrap Structural Equation Modeling

The bootstrap approach primarily assessed specific hypotheses regarding the mathematical structure of changes in central bank balance sheet movements with changes in exchange rates. This approach is an expansion of the PLS running window analyses and was utilized for its power to estimate the mean effects of changes in balance sheet holdings on exchange rates. A set of hypothesis are defined and are used to guide the reader into the methodology of this empirical section of this paper. These hypotheses denote the purpose of this section of this paper, which is to develop an empirical derivative of the data used in the PLS empirical study that can define a mathematical relationship between balance sheet holdings of central banks and exchange rates.

Referring to Table 1, models C and D utilize the bootstrap statistical method. These models used identical economic models to those employed in models A and B. Intuitively, these models employed similarly structured statistical models. The length of lags between the constructs that exist in these models are identical to those of Model A's. However, these models utilized same data but delineated by different dates.

The bootstrap method was applied to a modified data set composed of differing date delineations compared to the PLS analysis models. One set corresponds to the entire period of non-traditional monetary policy analyzed by this research (11/25/2008 to 5/15/2013), and one corresponding to dates delineated by the beginnings and endings of non-traditional monetary policies of the FED. Table 2 outlines these dates.

Equation 2 outlines the bootstrap algorithm in conjunction with the variables presented in Figure 6. Figure 6 is a simplified mathematical model of the actual one used in SmartPLS. For each data set, this paper utilized the SmartPLS bootstrap algorithm to compute 999 resamples of each data set; not including

Table 2

List of Date Delineations for Model D: Delineated by FED Non-Traditional Monetary Policy Announcements

Set Number	Set Identifier	Set Start Date	Set End Date
1	FED QE 1	11/25/2008	3/18/2009
2	FED QE 1 Expansion	3/19/2009	8/26/2010
3	FED QE 2	8/27/2010	6/21/2011
4	-No Active Policies-	6/22/2011	9/20/2011
5	Operation Twist	9/21/2011	6/19/2012
6	Operation Twist Expansion	6/20/2012	9/12/2012
7	FED QE 3	9/13/2012	12/11/2012
8	FED QE 3 Expansion	12/12/2012	5/15/2013

Note. Dates are inclusive. In addition, these are not indicative of dates of cases used in each data set. Models C and D introduced lags to account for CIP covering periods of balance sheet holdings and security yields.

the one original sample. Furthermore, for the 'case' parameter in each data set, this paper used numbers of cases equal to the number of days in each data set, e.g. the number of unique measurements for a particular indicator over the data set's period.

Equation 2. Bootstrap algorithm and accompanying hypotheses:

i = sample #
σ = standardized regression weight
X = the set of resampled standardized measured effects

$$o_1 = y_{1,2} \text{ x } y_{1,1} \Rightarrow \text{BOJ measured effect}$$
$$x_{1,i} = [y_{1,2}]_i \text{ x } [y_{1,1}]_i$$
$$[y_{1,2}]_i \in Y_{1,2} = \{[y_{1,2}]_1, [y_{1,2}]_2, ..., [y_{1,2}]_i\} \Rightarrow \text{¥ Sec. } (\sigma = 1) \rightarrow \text{E\$/¥ } (\sigma)$$
$$[y_{1,1}]_i \in Y_{1,1} = \{[y_{1,1}]_1, [y_{1,1}]_2, ..., [y_{1,1}]_i\} \Rightarrow \text{BOJ } (\sigma = 1) \rightarrow \text{¥ Sec. } (\sigma)$$
$$x_{1,i} \in X_1 = \{x_{1,1}, x_{1,2}, ..., x_{1,i}\}$$
$$o_2 = y_{2,2} \text{ x } y_{2,1} \Rightarrow \text{FED measured effect}$$
$$x_{2,i} = [y_{2,2}]_i \text{ x } [y_{2,1}]_i$$
$$[y_{2,2}]_i \in Y_{2,2} = \{[y_{2,2}]_1, [y_{2,2}]_2, ..., [y_{2,2}]_i\} \Rightarrow \text{\$ Sec. } (\sigma = 1) \rightarrow \text{E\$/¥ } (\sigma)$$
$$[y_{2,1}]_i \in Y_{2,1} = \{[y_{2,1}]_1, [y_{2,1}]_2, ..., [y_{2,1}]_i\} \Rightarrow \text{FED } (\sigma = 1) \rightarrow \text{¥ Sec. } (\sigma)$$
$$x_{2,i} \in X_2 = \{x_{2,1}, x_{2,2}, ..., x_{2,i}\}$$

$$\begin{matrix}\text{BOJ} = 1 \\ \text{FED} = 2\end{matrix} \mid X = \begin{Bmatrix} X_1 \\ X_2 \end{Bmatrix} = \begin{Bmatrix} x_{1,1}, x_{1,2}, \dots, x_{1,i} \\ x_{2,1}, x_{2,2}, \dots, x_{2,i} \end{Bmatrix}$$

BoJ Estimated Mean Standarized Measured Effect of the

$$\text{Pop.} \Rightarrow \frac{\sum_i^n x_{1,i}}{n} = \mu_1 \mid n = \text{\# of samples}$$

FED Estimated Mean Standardized Measured Effect of the

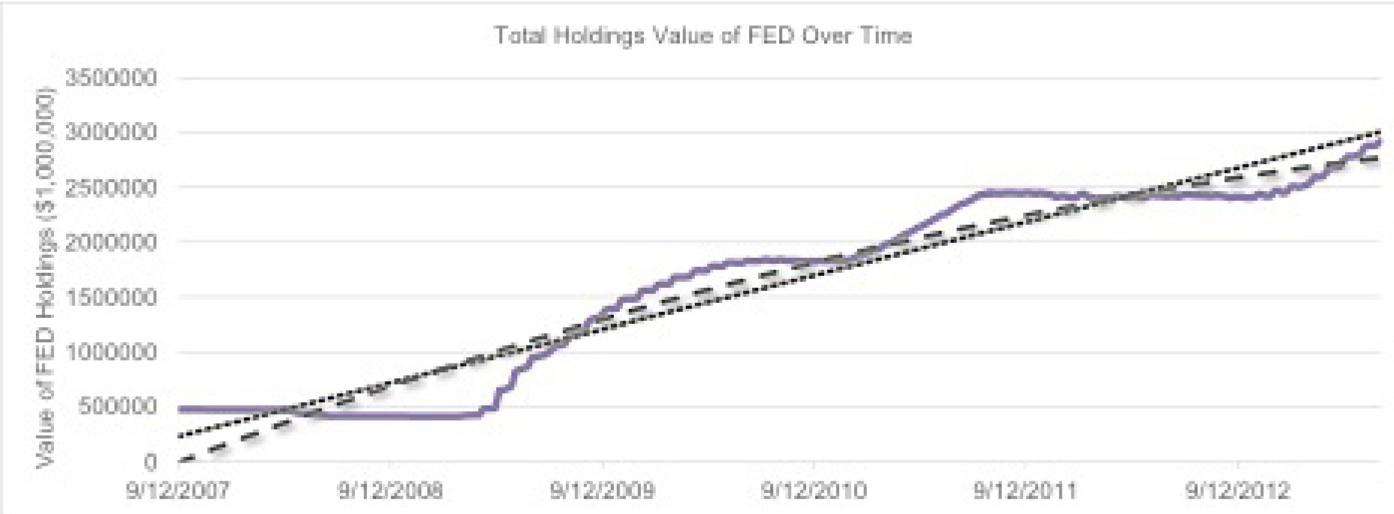
$$\text{Pop.} \Rightarrow \frac{\sum_i^n x_{2,i}}{n} = \mu_2 \mid n = \text{\# of samples}$$

$$H_0 : \mu_1 \geq 0 \land \mu_2 \leq 0$$

Given both bank balance sheet holdings increasing with respect to time

$$H_1 \text{ (\$ depreciation/ ¥)}: \mu_1 > 0 \land \mu_2 > 0$$
$$H_2 \text{ (¥ depreciation/ \$)}: \mu_1 > 0 \land \mu_2 < 0$$

Equation 2 proposes a number of hypotheses, one null and two alternatives based on the assumption that balance sheet holdings are increasing on average for both the FED and BoJ. (See Graphs 1 and 2 for evidence that over the period 11/25/2008 to 5/15/2013 balance sheet holdings for both banks are increasing on average.) H_0 (Null Hypothesis) defines an outcome of the bootstrap model that is counterintuitive to the way foreign exchange markets operate. The null hypothesis describes an outcome where the dollar/yen exchange rate is simultaneously appreciating and depreciating, assuming the balance sheet holdings of both central banks are increasing. The logical equation $\mu_1 \geq 0 \land \mu_2 \leq 0$ defines the null hypothesis; where μ_1 is the mean, estimate of the standardized regression weights (SRW), or total effect, between the BoJ's balance sheet holdings and the dollar/yen spot rate and μ_2 is that of the FED's. Simultaneous appreciation and depreciation in the spot rate is counterintuitive to the CIP and any such outcome would constitute some statistical discrepancy or failure in the model's design. H_1 on the other hand refers to an outcome in which the dollar is depreciating with



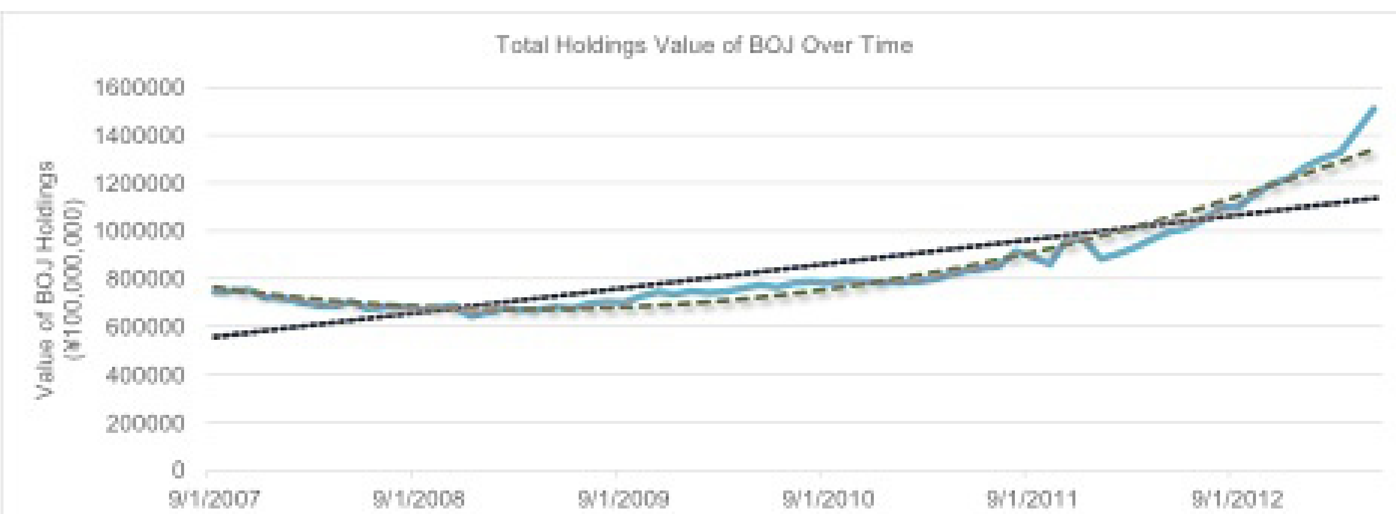
Graph 1. On average, the FED increased its holdings of assets over the period 9/12/2007 to 5/15/2013 as indicated by the linear trend line. However, the rate of increase in these holdings started to diminish around 9/1/2010 as indicated by the inflexion point of the second-degree polynomial trend line.

respect to the yen. In this case, both mean, estimated population SRWs are positive. In the case of the second alternative hypotheses, H_2, both mean, estimated population SRWs are negative. This case implies that the dollar is appreciating against the yen.

In the case that balance sheet holdings of the FED and BoJ, if both are not increasing simultaneously, this research will conduct further analysis to extrapolate from the initial hypotheses postulated. There indeed exist specific cases through the time periods 7/28/2008 to 5/15/2013 that balance sheets of either bank are decreasing (Refer to Graphs 1 and 2).

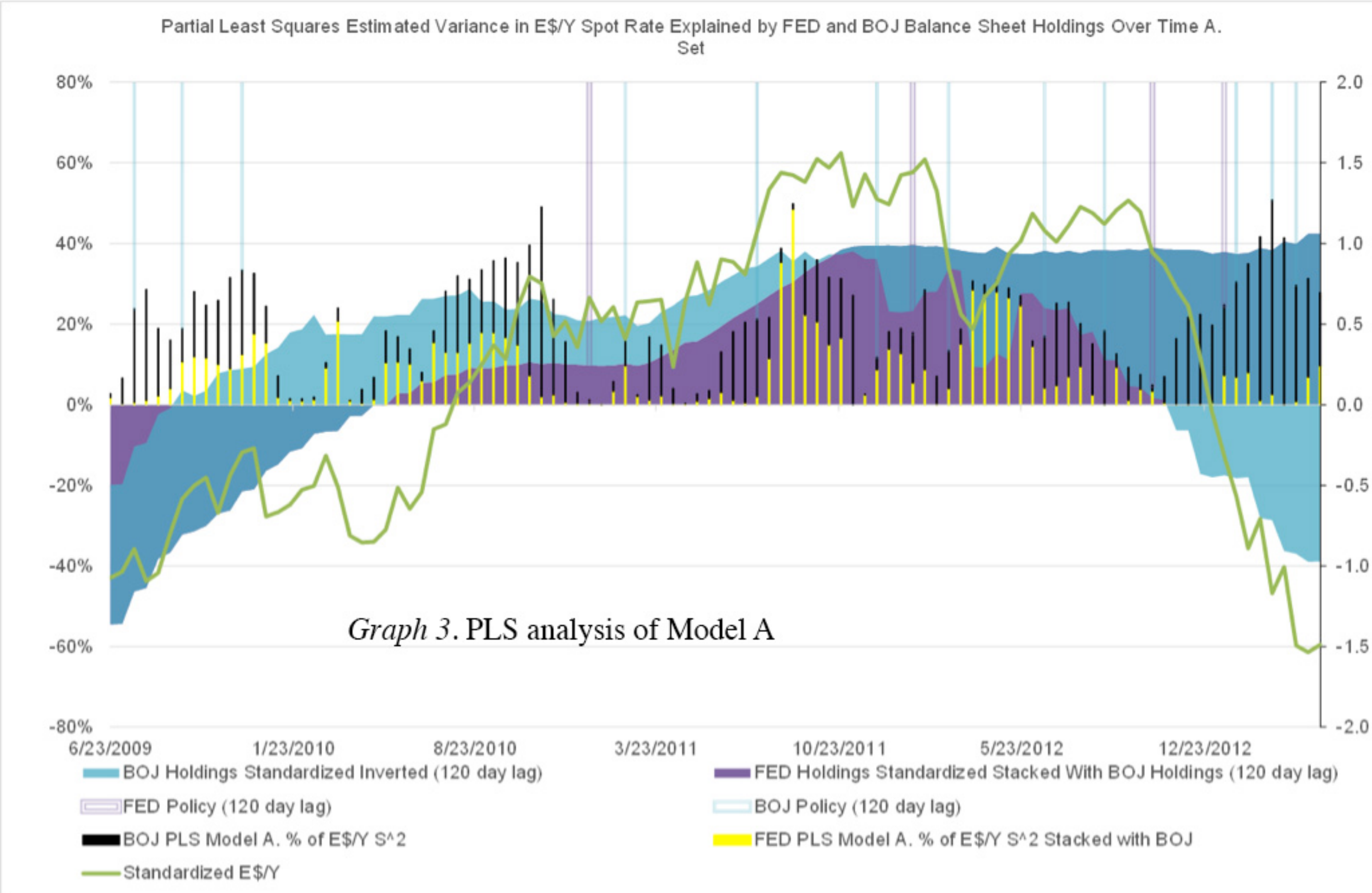
Data

This work utilized Indicator data from 7/28/2008 to 5/15/2013, 120 days before the beginning of QE 1 operations: 11/25/2008 (Federal Reserve Bank of St. Louis, 2013). For general indicator data like exchange rates, this researched pulled data from the Trading Economics database (2013). The 3-month CD rate, 3-month LIBOR rate, and 3-month interbank rate for the



Graph 2. From 9/15/2007 to 5/15/2013, on average, the BOJ increased it holdings of assets over time. However, from around 9/15/2007 to 3/1/2009, referencing the second-degree polynomial trend line, the BOJ was decreasing their holdings of assets. After around 3/1/2009, the value in the BOJ's assets started to increase at an increasing rate

Inquiry: The University of Arkansas Undergraduate Research Journal, Vol. 17 [2014], Art. 6



Graph 3. PLS analysis of Model A

U.S. and Japan were retrieved from the Federal Reserve Economic Database (FRED) (2013). The balance sheet holdings of mortgage backed securities (MBS), and U.S. note/bond treasury securities were also retrieved from the FRED database. Data regarding BoJ holdings of 1 year and 30 year Japanese government bonds, commercial papers, corporate bonds, stocks, exchange traded funds (ETF), and Japan real estate investment trusts (J-REIT) held as trust property were retrieved from the Bank of Japan Time-Series Data Search database (2013). U.S. 1 year and 30 year treasury security yields originate from the U.S. Department of the Treasury Resource Center (2013). 1 year and 30 year Japanese government bond yield data were retrieved from the Ministry of Finance Japan's Japanese Government Bonds Data Interest Rate database (2013).

All indicators were aggregated frequency wise into one-day increments. This research accounted for missing data or data of different frequencies by the substituting the earliest available measurement for that indicator given a particular date in time.

This research parsed data by pre-determined dates and lags according to the defined models in Table 1 and saved them into comma-delineated sheets (.csv) for importation into SmartPLS. The data were then assigned to constructed models like that of Figure 2.

Results and Discussion

The following section describes the results from the four models derived from the previous sections. Each model delineates a section below and are in alphabetical order by the model identifier. Table 1 summarizes the models employed by this research.

Model A PLS 2 Week Running Window

Referring to Graph 3, all 102 PLS algorithm computations for both the FED and the BOJ from Project A have been inputted as stacked clustered columns. The yellow-clustered columns represent the FED's balance sheet holdings of MBS and notes/bonds percent correlation with the variance in the dollar/ yen exchange rate. The BoJ's balance sheet holdings of 1 year Japan bills, 30 year Japan bonds, corporate bonds, commercial paper, ETFs, J-REITS, and stocks percent correlation with the variance in the dollar/ yen exchange rate are filled as black and stacked on top of that of the FED's. The stacking is appropriate because the combined variance accountancy of both banks is intuitively a single output from the SmartPLS program. A measure for each bank exists because of the measures taken to reduce multi co-linearity. The stacking also provides a convenient aid in evaluating the potency of each of these central bank's programs about the exchange rate. It is important to keep in mind that the measured correlations drawn on the graph refer to balance sheet holdings 120 days before the measurement of the dollar/yen exchange rate, also drawn on the graph in green.

The purple and blue shaded regions in the background of the graph represent the level of the FED's (purple shade) and BoJ's (blue shade) monetary programs, as measured by the dollar value of their assets at the 120-day lag corresponding to the date axis. The lag in the balance sheet holdings measurement is consistent with the PLS statistical model's 120-day lag and the clustered column's 120-day lag. This project standardized the balance sheet holdings of each bank over the period starting 9/19/2007 and ending 5/15/2013. On the graph, the FED's shaded area ascends the plotted area as its balance sheet expands and vice versa, while the BoJ's shaded area has been inverted so that its area descends the plotted area as its balance sheet holdings expand, overlapping any FED actions. The purpose of the inversion was to stay consistent with the CIP theory of inverted effects of two countries' currency denominated yields when compared in conjunction with the current exchange rate between those two countries. Furthermore, the graph has drawn the standardized dollar/yen exchange rate as the green line traversing the length of the graph. The date of the dollar/yen exchange rate measurement corresponds to the exact date on the date axis; this is consistent with the statistical model where the exchange rate is a zero day measurement. In addition, exchange rate was standardized over the period starting 8/27/2008 and ending 5/15/2013.

Blue and purple lines populating the upper height of the graph delineate dates of non-traditional monetary program introductions or expansions 120 days before the measure on the date axis, consistent with the stacked columns and shaded areas. The blue lines represent BOJ program introductions or expansions while the purple lines represent FED program introductions or expansions.

It is apparent in Graph 3 that there is a powerful relationship between changes in balance sheet holdings of either the BoJ or FED and the dollar/yen exchange rate. Increases in the shaded areas correspond to a sharp rise in the exchange rate over the length of the graph. This relationship is even powerful in the short run where volatility in balance sheet holdings is consistent with volatility in the exchange rate. This relationship is solidified by the stark rises in the variance accountancy of the exchange rate by balance sheet holdings during abrupt changes in the exchange rate.

Model B PLS 2 Week Running Window

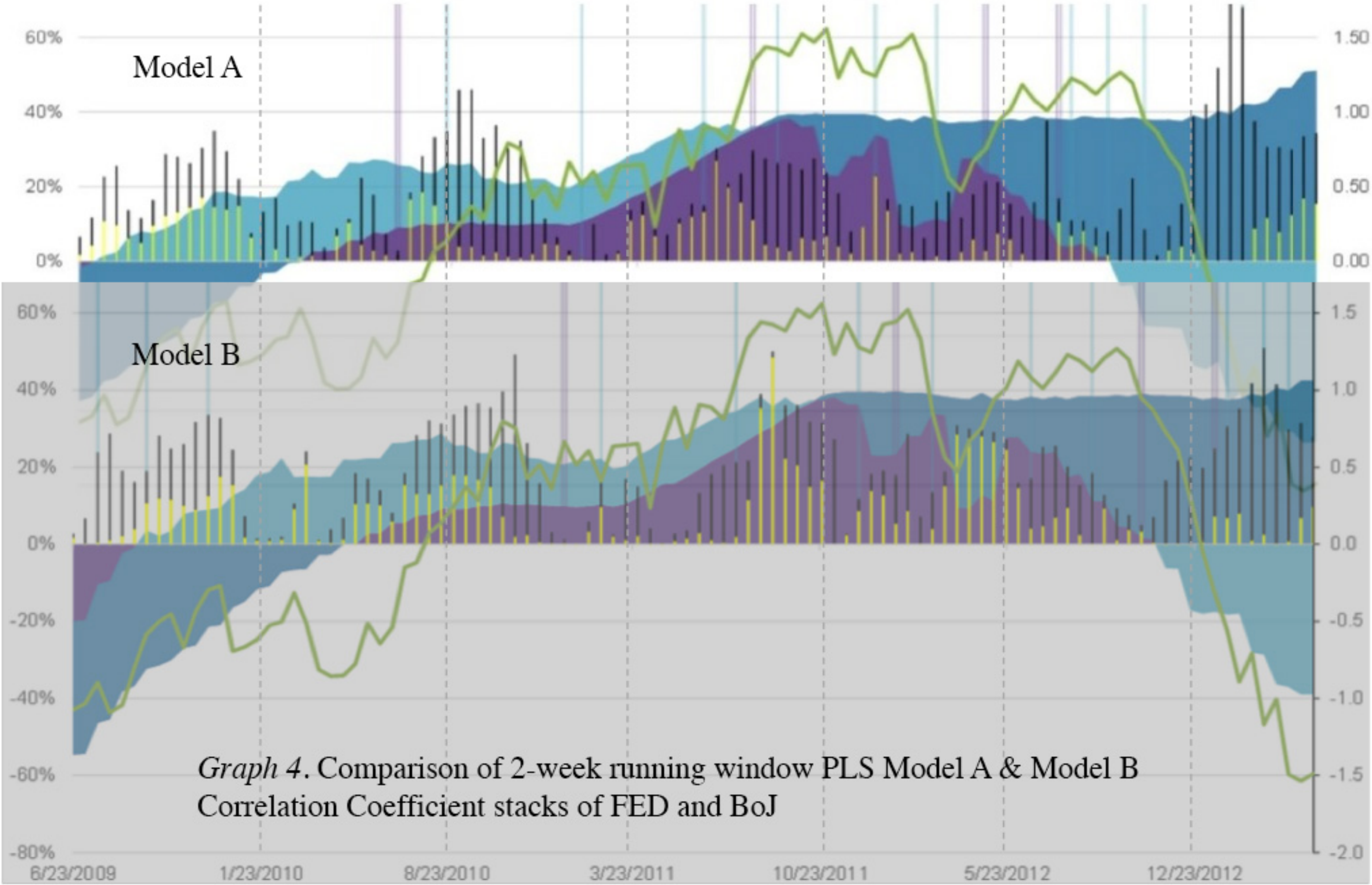
As a means of making sure the lags introduced into the statistical model in project A are appropriate, another PLS analysis was conducted using shorter lag dates. If consistent with this research's initial CIP lag tests, the results of the shorter lag dates should cause the correlations among the balance sheet holdings and the spot rate to diminish or not significantly change due to actors on exchange rates not having enough time to cover their positions.

Referring to Graph 4, the patterns in the correlations among the FED and BoJ balance sheet holdings and the dollar/yen spot rate appear to be similar to that of Project A's. The oscillation patterns in the correlations among the balance sheet holdings and the exchange rate exists among roughly the same periods in both graphs. Furthermore, in Graph 3, relative to Graph 1, the magnitudes of the humps are roughly the same around the 1/23/2010, 8/23/2010, and 3/23/2011 date markers. Furthermore, there is a significant decrease in the magnitudes of the humps around the 10/23/2011 and 5/23/2012 date markers. Interestingly, the magnitude of the correlation stacks around the 12/23/2012 date marker increased significantly.

It is apparent that Model A provides significant evidence for a relationship between BOJ and FED balance sheet holding changes and the dollar/yen exchange rate.

Model C Total Time Bootstrap Analysis

Project C utilized the bootstrap analysis method. This analysis further evaluated the possible relationship between changes in balance sheet holdings by the FED and BOJ and the exchange rate found in the PLS structured statistical analysis (Models A and



Graph 4. Comparison of 2-week running window PLS Model A & Model B Correlation Coefficient stacks of FED and BoJ

B). More specifically, this analysis provides a direct mathematical interpretation of the significance, level, and direction of any possible relationship between central bank balance sheet holdings and exchange rates that this research could then evaluate with respect to a proposed hypothesis.

This paper conducted Model C over the period starting 11/25/2008 and ending 5/15/2013. Project C only consists of one data set. This data set represents the majority period for which the FED has been conducting non-traditional monetary policy. This research utilized the SmartPLS program to compute resampled standardized regression weights with respect to the original samples. In total, there are 1000 samples with corresponding regression weights between all possible construct relationships.

Next, this research evaluated the t-statistics (computed by taking the original sample and dividing it by the standard error of the resample distribution) of each distribution with respect to the 95% confidence interval. (Degrees of freedom equals 1000 so corresponding two-tailed t-statistic at the 95% confidence interval is around 2.000.) This research considered any relationship with a t-statistics less than 2.000 to be not significant. If a particular relationship was significant, then this research would evaluate the mean total effects for the resample distribution with respect to the bootstrap hypothesis shown in Equation 2.

In the case of Project C, both t-statistics were greater than 2.000 (refer to Table 3). This research then evaluated the mean total effects as well as confidence intervals of these two distributions with respect to the two hypotheses proposed for the bootstrap method.

Referring to Table 6, the analysis fails to reject the null hypotheses. Reason being, over the time period 11/25/2008 and ending 5/15/2013, the total effect estimation of the BoJ's balance sheet holdings effect on the exchange rate is positive. Extrapolating, this implies that balance sheet holdings negatively related to security yields as balance sheet holdings expanded over the period. Furthermore, yields negatively related to the dollar/yen exchange rate, meaning the yen appreciated against the dollar, assuming balance sheet holdings of the BoJ increased. An analogous situation occurs with the FED balance sheet holdings and the dollar/yen exchange rate. Increases in holdings corresponded to an appreciation in the dollar against the yen.

The fact that this analysis failed to reject the null hypotheses is not surprising given the extremely wide

Table 3

Model C Resample Distribution Summary Statistics and Confidence Intervals

Relationship Identifier	x[a]	μ[b]	σ[c]	t_a[d]	Lower Bound[e]	Upper Bound[f]	H	Hypothesis
BOJ Node -> E$/Y	0.590	0.590	0.022	26.304	0.545	0.635	$\mu_1 > 0$	H_0
FED Node -> E$/Y	-0.402	-0.402	0.026	15.360	-0.455	-0.350	$\mu_2 < 0$	

[a] Original sample total effect
[b] Mean estimation of the population total effect based on resample data
[c] Standard deviation of the estimated population total effect
[d] T-statistic ($x/STER$); STER is the standard error of the estimation of the population total effect
[e] Lower bound of the two-tailed 95% confidence interval
[f] Upper bound of the two-tailed 95% confidence interval

fluctuation in the exchange rate over the several year period. The next project (Project D) explores a more in depth bootstrap analysis, with periods partitioned by FED non-traditional monetary policy announcements.

Model D Bootstrap Analysis FED Project

Equation 2 evaluates the hypotheses presented in conjunction with the data presented in Table 4 for the data sets outlined in Table 2.

Apparent in Table 4 is the broad fluctuation in the direction of spot rate movements accounted for by respective central bank balance sheet movements. The changes in the accepted hypothesis between successive time-periods depicts this. This is not surprising given the wide fluctuation in the exchange rate and the level of balance sheet holdings of both the FED and BoJ over the large time period and even between the shorter delineations used in this project.

Because the bootstrap structural equation modeling used in this project is a direct expansion of that of the PLS projects, this research was able to present a more condensed graphical representation of the estimated population total effects with respect to the PLS variance estimation graph. Figures 7 through 12 of Graph 4 are condensed graphical summaries of these total effects (Graph 4 is a composite of these figures. It provides a context from which this analysis derived these figures from). Note, because the Bootstrap analysis started 90 days before the PLS analysis, there only exists limited corresponding time-periods in the PLS analysis that could be used for the purposes of overlaying the analyses. Nevertheless, the time-periods have been presented for which data is available; these include sets “2. FED QE 1 Expansion” through “7. FED QE 3”.

Looking at Figures 7 - 12 and the corresponding entries in Table 4 (relationship identifiers 2. – 7.), linear trend lines of the exchange rate have been overlaid into the graph clips. In addition, Figures 7 – 12 include a yellow, elevated line that represents the combined, standardized quantity of FED and BoJ balance sheet holdings. An increase in FED holdings, holding the BoJ’s constant, would push the line upwards, while an increase in BoJ holdings, holding the FED’s constant, would push the line downwards. Mathematical analysis

Table 4
Model D Resample Distribution Summary Statistics and Confidence Intervals

Relationship Identifier	x[a]	μ[b]	σ[c]	t_a[d]	Lower Bound[e]	Upper Bound[f]	H	Hypothesis
1.								
BOJ Node -> E$/Y	-0.077	-0.072	0.134	0.576	-0.340	0.196	$t_a < 2$	H_1
FED Node -> E$/Y	0.644	0.642	0.131	4.906	0.380	0.904	$\mu_2 > 0$	
2.								
BOJ Node -> E$/Y	0.931	0.924	0.096	9.718	0.733	1.116	$\mu_1 > 0$	H_0
FED Node -> E$/Y	-0.217	-0.210	0.093	2.340	-0.396	-0.024	$\mu_2 < 0$	
3.								
BOJ Node -> E$/Y	-0.331	-0.334	0.047	7.115	-0.427	-0.240	$\mu_1 < 0$	H_2
FED Node -> E$/Y	-0.049	-0.049	0.025	1.967	-0.099	0.002	$t_a < 2$	
4.								
BOJ Node -> E$/Y	0.595	0.595	0.078	7.667	0.440	0.750	$\mu_1 > 0$	H_0
FED Node -> E$/Y	-0.221	-0.223	0.079	2.791	-0.381	-0.064	$\mu_2 < 0$	
5.								
BOJ Node -> E$/Y	0.077	0.075	0.026	3.001	0.024	0.127	$\mu_1 > 0$	H_1
FED Node -> E$/Y	0.745	0.651	0.361	2.064	-0.070	1.373	$\mu_2 > 0$	
6.								
BOJ Node -> E$/Y	0.420	0.432	0.288	1.458	-0.143	1.008	$t_a < 2$	H_0
FED Node -> E$/Y	0.003	0.001	0.143	0.022	-0.285	0.287	$t_a < 2$	
7.								
BOJ Node -> E$/Y	-0.006	-0.012	0.083	0.069	-0.178	0.155	$t_a < 2$	H_2
FED Node -> E$/Y	-0.545	-0.545	0.095	5.734	-0.735	-0.355	$\mu_2 < 0$	
8.								
BOJ Node -> E$/Y	-0.629	-0.629	0.041	15.434	-0.711	-0.548	$\mu_1 < 0$	H_2
FED Node -> E$/Y	-0.156	-0.156	0.040	3.901	-0.236	-0.076	$\mu_2 < 0$	

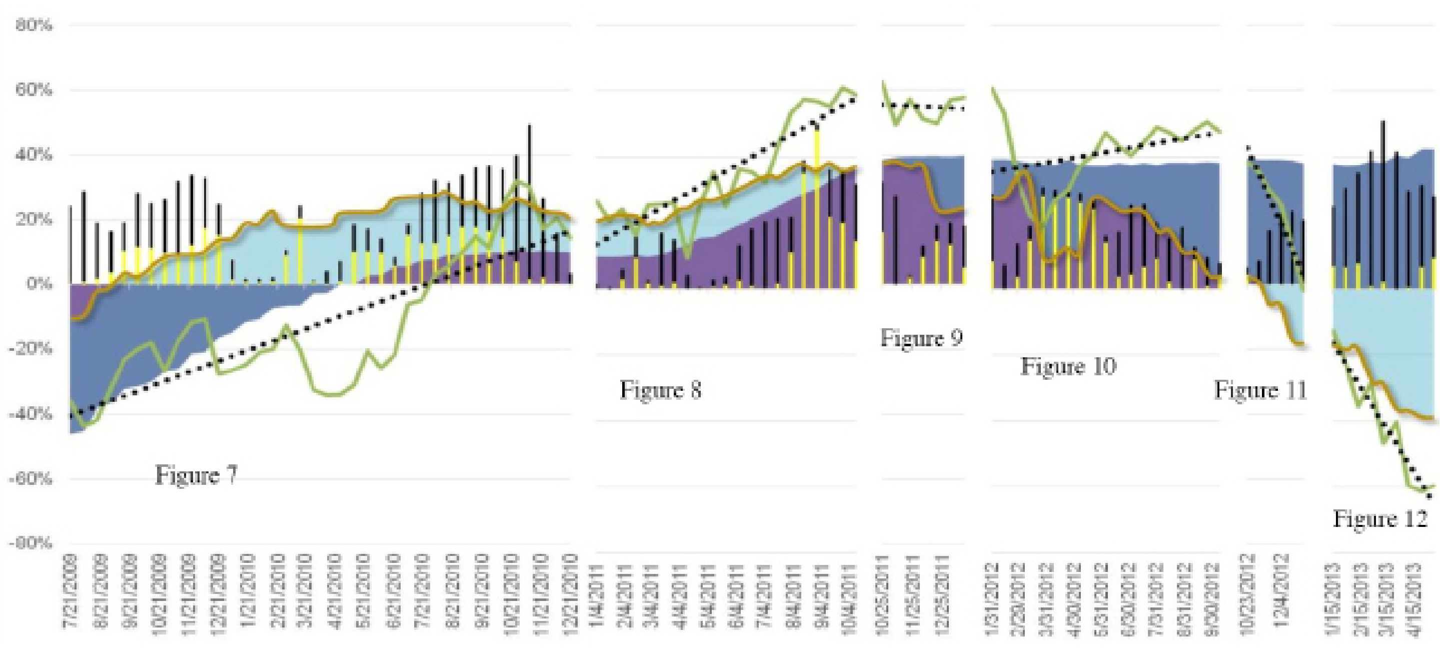
[a] Original sample total effect
[b] Mean estimation of the population total effect based on 999 resamples of original data with case numbers for individual resamples equal to the original data's corresponding number of cases
[c] Standard deviation of the estimated population total effect
[d] T-statistic ($x/STER$); STER is the standard error of the estimation of the population total effect
[e] Lower bound of the two-tailed 95% confidence interval
[f] Upper bound of the two-tailed 95% confidence interval

was used to analyze the magnitudes in the changes of the background shaded areas of each bank with respect to changes in the exchange rate (also corroborated by the PLS variance accountancy) in conjunction with the relationship postulated by the estimation of the population total effect. These two relationships were evaluated with respect to each other to determine if the graphical relationship postulated in the PLS analysis are mathematically substantiated by the bootstrap analysis.

In Figure 7, the bootstrap analysis failed to reject the null hypothesis. Figure 7 defines the period of FED QE 1 expansion policy in the United States starting 3/19/2009 and ending 8/26/2010. The two partial hypothesis produced by the bootstrap algorithm for this time period are counter intuitive as they imply simultaneous appreciation and depreciation in the dollar/yen exchange rate when assuming balance sheet holdings of both banks are increasing. A closer look at Figure 7 will reveal that linearly defining a relationship for this large time-period is difficult, thus, it is not surprising that the bootstrap algorithm failed to reject the null.

However, the general trend of the exchange rate (the dotted line) implies a long-term depreciation in the dollar; this trend corroborates the positive estimation of the population total effect of the BoJ node if not accounting for the fact that the BoJ's balance sheet holdings are actually decreasing on average during this period. The FED node effect is negative however and implies dollar appreciation because of increases in balance sheet holdings. It would seem that, during this time-period, the BoJ was scaling back their non-traditional monetary programs with respect to the scale of the FED's. The stark rise in the prominent edge of the background shade substantiates this. (Note, to read the background shade, the BoJ's holdings are subtracted from the FED's so that you read the prominent edge of the blue shade, this is the dark yellow line in the figure.) The null relationship seems to make sense, in that the scaling back of monetary transactions by the BoJ is effectively magnifying the FED's QE 1 expansion effects on the exchange rate. Consequently, this is causing a general depreciation in the value of the dollar with respect to the yen. That is, although the FED's estimation of the total effect implies its increases in balance sheet holdings are causing dollar appreciation. Although the FED's first foray into non-traditional monetary policy was not as substantial as the program's later successors, the scaling back of central bank transactions by the BoJ during this time period effectively outweighed any appreciative effects the model estimation might have substantiated by assigning a negative estimation of the population total effect of the FED.

Referring to Figure 8, the general appreciating trend in the value of the yen continues. The negative partial hypothesis of the BoJ and non-significant FED partial hypothesis, however, do not lend themselves to induce an appreciation in the yen. In fact, based on the estimation of the population total effect, one would believe that the yen would depreciate during this time-period. The upward sloping trend line of



the spot rate coupled with a stark rise in FED non-traditional monetary policy accountancy of exchange rate variation in the latter half all demonstrate a counter to the population estimations. The conflicting results of this model could be a result of the volatile nature of the exchange rate during this period.

Continuing on to Figure 9, the period between 6/22/2011 and 9/20/2011 constitutes a period of no active policies by the FED. The relatively short time period and fact that during this time-period the FED was not conducting any non-traditional monetary policy makes the results of the bootstrap estimations of the population total effect unexciting. During this period, you could argue that there was a slight depreciation in the yen relative to the dollar, as highlighted by the dotted trend line. Indeed, the sudden shift in the magnitude of the balance sheet holdings of the BoJ could corroborate this argument, but the fact that the exchange rate seems to hold steady during this period and the fact that the null hypothesis failed to be rejected both make it difficult to define a possible relationship during this time period.

Next, referring to Figure 10, the FED's Operation Twist program and the dates that it was active (9/21/2011 – 6/19/2012) are analyzed. The Operation Twist program was a credit-easing monetary program as opposed to a quantitative easing one. According to the bootstrap model and the accompanying hypothesis, of which both partial hypotheses are significant, the balance sheet changes during this time-period were conducive to dollar depreciation relative to the yen. Starting from the left, sharp depreciation in the dollar follows sudden appreciation in the dollar. This almost resembles "over shooting" in which investors over adjust to market conditions and subsequently readjust their positions to a more moderate one. This sharp depreciation is simultaneously occurring while the exchange rate variance accountancy by the FED's balance sheet changes, rise significantly. The large yellow stacks highlight the latter. It is interesting that the large changes in the BoJ balance sheets during this period do not statistically arise to a depreciation in the yen; although the population total effect of the BoJ node is hardly large. However, it seems obvious that we would expect to see depreciation in the yen after the large downward swath of blue shade. This appears to occur during the, roughly, first third of Figure 8. Nevertheless, it would seem the FED's monetary programs are certainly more potent against the exchange rate during this period. This is perhaps a consequence of the credit-easing programs of the FED as opposed to the BoJ's mainly quantitative ones at that time. Bolstering this conclusion is the fact that the BoJ's balance sheet holding changes do not statistically account for much of the variation in the exchange rate during this period.

Next, Figure 11 refers to the period in which the FED expanded their Operation Twist credit-easing program. Both estimations of the population total effect during of this period are not significant. The BoJ node is significant, however, at around the 85% confidence level. The positive estimation implies appreciation in the yen relative to the dollar. This does not seem to make sense considering the large increase in BoJ holdings during this period and the corresponding drop in the exchange rate, e.g. yen depreciation. In addition, the considerable up trend in BoJ balance sheet holdings accountancy of exchange rate variation during this period does not seem to substantiate the bootstrap's outcomes.

Now referring to Figure 12, it is apparent that the large influx of liquidity produced by the BoJ's balance sheet holdings should be causing a large depreciation in the yen relative to the dollar. However, there is no significant relationship between BoJ balance sheet holdings and the exchange rate during this period. In fact, it would appear that the FED's balance sheet holding changes are having a much more substantial effect on the exchange rate than the BoJ's. This could be a manifestation relatively constant FED holding increases during this period. The inherent consistency in the FED's QE 3 program could have indirectly amplified any effects the BoJ's holding increases might have had on the exchange rate.

Conclusion

It would seem that linearly defining a relationship between the balance sheet holdings of the BoJ and FED and the dollar/yen exchange rate is extremely difficult. In fact, there may be some nonlinear relationship in play here in which outside investors are either exponentially amplifying the effect that these programs have on the exchange rate, or in effect nullifying them as they take speculative actions against central bank programs. The nullifying effect may be more applicable to the BoJ's actions where, as Blinder said, when a country exists near or at a liquidity trap, central bank transactions must become massive to invoke any kind of significant effect on domestic inflation (Blinder, 2000). Nevertheless, there most definitely appears to be some relationship between central bank non-traditional monetary programs and exchange rates. This is directly apparent throughout the PLS analysis results and graphically throughout Graph 3.

The subject of relating non-traditional monetary policy to exchange rates is indeed difficult. However, this research provides compelling evidence that a relationship does exist. Future research will define and test particular models that could help explain the exact relationship between these two.

References

Bank of Japan. (2013). *Bank of Japan(BJ) Time-Series Data Search.* Retrieved from http://www.stat-search.boj.or.jp/index_en.html

Blinder, A. S. (2000). Monetary policy at the zero lower bound: Balancing the risks. *Journal of Money, Credit and Banking, 32*(4), 1092-1099. Retrieved from http://www.jstor.org/stable/2601162.

Chaboud, A. P., & Wright, J. H. (2004). Uncovered interest parity: It works, but not for long. *Journal of International Economics, 66*(2005), 349–362. doi:10.1016/j.jinteco.2004.07.004

Federal Reserve Bank of St. Louis. (2013). *Federal reserve economic data.* Retrieved from http://research.stlouisfed.org/fred2/

John, R. (2002). The C-OAR-SE procedure for scale development in marketing. *International Journal of Research in Marketing, 19,* 305-335.

Ministry of Finance Japan. (2013). *Japanese Government Bonds Data Interest Rate*. Retrieved from http://www.mof.go.jp/english/jgbs/reference/interest_rate/index.htm

Tabachnick, B., & Fidell, L. (2007). *Using multivariate statistics* (Fifth ed.). Boston: Pearson Education Inc.

Taylor, M. P. (1987). Covered interest parity: A high-frequency, high-quality data study. *Economica, 54(*216), 429-438. Retrieved from http://www.jstor.org/stable/2554178

Thornton, D. L. (1989). Tests of covered interest rate parity. *Federal Reserve Bank of St. Louis Review, 1,* 55-66. Retrieved from http://research.stlouisfed.org/publications/review/89/07/Tests_Jul_Aug1989.pdf

Trading Economics. (2013). *Source of indicator data* [Japan, U.S.]. Retrieved from http://www.tradingeconomics.com/

U.S. Department of the Treasury. (2013). *Resource Center* [Daily Treasury Yield Curve Rates]. Retrieved from http://www.treasury.gov/resource-center/data-chart-center/interest-rates/Pages/